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USE OF THE MONTE CARLO TECHNIQUE FOR THE ENGINEERING ECONOMIST

by

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Monte Carlo methods may be considered as the application of random sampling techniques in the evaluation of a situation where one or more of the variables under study is subject to random behavior. Monte Carlo methods have a long history of use in mathematics and the physical sciences, finding their applications in those cases where direct computations are extremely difficult or impossible but where approximate solutions are readily obtained by means of probabilistic models. An important application in recent years is in the field of quantum mechanics. As in the case of linear programming and various other mathematical techniques, there has been some use made of Monte Carlo methods in the field of management in recent years, these mathematical techniques being loosely referred to as operations research. However, not as much attention has been paid to Monte Carlo methods as some of the other techniques. It would seem that a more wide-spread use could be made of these methods because of the large numbers of complex factors that prevail in industrial situations which make the use of probabilistic models almost imperative in an analytic study.

* Mr. Eubank is responsible for the body of the paper.
Mr. White is responsible for the introduction, conclusion and appendix.

Monte Carlo methods, for the most part, have been used in industry to set up models in the study of one or more factors subject to random behavior. In the example discussed in this paper, there are two such factors; the amount of daily scheduled throughput of crude oil at the refinery and the number of ships arriving daily at the terminal. The underlying patterns of the distributions of these factors was ascertained, enabling the analyst to set up "typical" operating conditions (the model) from which he could predict how often tankers would be delayed in loading, the frequency of cutbacks of production due to lack of crude oil at the refinery, and the amounts of the cutbacks, considering the physical limitations of the equipment. This study might be useful in determining such matters as the amounts of storage facilities required to avoid holding tankers and/or to enable the refinery to operate without cutbacks. Thus the illustrative example can be used to provide data to answer the following question: Will it pay to increase tank storage capacity at the refinery and/or tanker terminal? To make a decision, estimates need to be made of how much time tankers are delayed because oil is not available to load them at the terminal and how much of refined products are lost at the refinery by runs being cut back for lack of crude. A dollar value can then be set (1) on the cost of tanker delay and (2) on the cost of cutting back the refinery runs. Against this can be balanced the cost of building additional tank storage capacity in both locations. Since the objective of the presentation of this example is to illustrate the use of a Monte Carlo model, dollar values are not used.

Solving the problem first in physical terms prior to using a dollar measuring scale has certain advantages. For instance, the introduction of a dollar measuring scale at the outset requires approximations which tend to obscure the underlying physical aspects of the problem. Expressed differently, solving the problem first in physical terms highlights the assumptions and restrictions introduced in the solution. These physical restrictions may have a significance in refinery operation far above the dollar figures that might be attached to them.

Other than in the field of physical sciences, there is not an extensive amount of literature dealing with practical applications of Monte Carlo methods. Some of the applications discussed in the literature are: predicting the frequency of valve failures in a preventive maintenance study (1); predicting the probability of successful Ground-Controlled Approach landings under specified weather conditions (2); experimental verification of Lanchester's Square Law of military tactics[1] (3); and a general discussion of Monte Carlo techniques. We may speculate that further industrial applications may be found in such matters as determining the frequency of incoming orders and the effect on utilized plant capacity, and predicting the variability in sales and its effect on finished products inventories, all of interest to the engineering economist.

[1] "The over-all effectiveness of a given force equals the average effectiveness of the individual units multiplied by the square of the number of units engaged." Excerpt from article, Reference 3.

WHAT ARE MATHEMATICAL MODELS?

We are all familiar with many types of physical models. In the petroleum industry, before money is invested in a commercial sized venture, a new process is usually tested using smaller physical models - bench scale laboratory tests, pilot plants and semi-commercial sized units. Each of these models can be manipulated to find out how the process behaves under various input conditions. That is, if we want to know what will happen to the product yield in the commercial sized plant if temperature is increased, we can increase the temperature in one of the models and observe its effect on yield. The advantage of using models is that they may be manipulated more cheaply and quickly than the commercial plant. The more accurately the model simulates the commercial sized plant, the more confidence we can have that the effect observed in the model will also be found in the commercial plant.

Another kind of model not so familiar, or at least not so quickly recognized, is a mathematical model. A mathematical model is one or more equations that describe an actual operation mathematically. Like the physical model, it can be manipulated to show what effects a given change will have. A mathematical model which most people will recognize is Einstein's famous equation, $E=mc^2$. This model says that when mass is converted to energy, the energy which is released, E, is equal to the product of the change in mass, m, and the square of the velocity of light, c^2. I am sure we all agree that if we want to know how much energy is released when a given amount of mass is converted into energy, we can obtain the answer much more quickly and cheaply using the equation

than by building and exploding an atomic bomb. Other similar examples are: 1) D = R x T which says that the distance traveled, D, by an object moving at constant speed, R, for a time, T, is equal to its speed times the time; 2) $2H_2 + O_2 = 2H_2O + Q$ which says that two parts of hydrogen will combine with one part of oxygen to produce two parts of water plus energy; and 3) W = 18% (G - 13N) which is the formula for calculating the federal income withholding tax, W, from the weekly gross pay, G, and the number of exemptions, N.

All of the above examples are of systems which have only one possible mathematical model to describe their behavior. Many systems behave differently at different times. That is, sometimes one mathematical model will describe their behavior, and other times another model will describe their behavior. In some cases, if we know the state of the system we can predict which model will fit. In these cases a "decision rule" can be formulated to select the appropriate model .. Other operations are such that it is impossible to predict which mathematical model will fit their behavior even if we know the state of affairs. In these instances, we have a situation which can possibly be handled by Monte Carlo methods. Decision rules and Monte Carlo methods form our next two topics.

WHAT ARE DECISION RULES?

Suppose a manufacturing plant consumes exactly 1,000 barrels a day of fuel oil. A mathematical model of their fuel oil inventory situation could then be:

$$T = Y - 1{,}000$$

Here Y is yesterday's closing inventory and T is today's closing inventory. So far, this example is just like the single model examples above. Now, suppose the management of this plant always orders a 10,000 barrel delivery whenever the closing inventory is less than 3,000 barrels, and this delivery is always made on the next day. Now we have a system which has two possible models, either

$$T = Y - 1{,}000$$

or

$$T = Y - 1{,}000 + 10{,}000$$

However, if we know the state of the system (that is, if we know Y), we then know which model fits the system (we know which equation to use). Stated in mathematical form:

$$\begin{aligned} T &= Y - 1{,}000 \quad \text{if} \quad Y \geqq 3{,}000 \\ T &= Y + 9{,}000 \quad \text{if} \quad Y < 3{,}000 \end{aligned}$$

The management's fuel ordering policy is known as a decision rule, and the mathematical expression for that decision rule is the pair of inequalities on the right above.

Of course, most decision rules are much more complex than the above example. Also, although many real operations seem to be or should be of the nature we have been discussing, the people actually making the decisions have seldom formulated definitive decision rules to describe their actions. Instead, they use a sort of "seat of the pants" technique. One of the biggest problems in mathematical model building is what to do in cases like this. Usually a definitive decision rule was not formulated by the real-life decision maker because the situation could be too complex. Fortunately for study purposes, it often happens that a comparatively simple decision rule will do at least as well

as the "seat of the pants" technique. Of course, if a rule can be formulated which will do better, we should try to sell its use in the real-life situation.

WHAT IS THE MONTE CARLO TECHNIQUE?

Many of our problems involve factors which cannot be predicted exactly. However, we can often determine the probability of occurrence of all of the possible values of these unpredictable factors. The most probable answer to the problem can then be obtained by evaluating the operation for each of these possible values as if it were exact, and then weighting these outcomes by their probabilities of occurrence.

As an example, suppose we are studying an operation, the behavior of which is dependent upon many things including the length of a tanker voyage from Baton Rouge, Louisiana to Bayway, New Jersey. From past data we can find that a certain fraction of the voyages takes 100 hours, another fraction takes 101 hours, and so on. Now, from these data, we construct a group of numbers, including all of the possible lengths of voyages. The number of times each voyage length appears in this group will be proportional to the probability of that voyage length as actually occurring in reality. That is, if past data shows that 5% of the voyages are made in 100 hours, then 5% of our group of numbers would be 100's. Next we simulate on paper what might happen to the operation over a long period of time. Each time a voyage is indicated in our paper simulation, we choose at random[1] (much as drawing

[1] Another example of the choice of random numbers for this purpose appears in the Appendix.

from a hat) one of the numbers of our group. Then we calculate the result as if that particular voyage were exactly as long as the number we drew. If we do this for a long enough period (enough voyages) then the average effect we obtain is the most probable behavior of the operation to expect in the future.

A study carried out in the above way is said to be solved by the Monte Carlo technique. The group of numbers representing the possible values of the unpredicatable factor is known as a "population" and the process of choosing a number from the population is known as "random sampling". In the above example the population was constructed from past data. If past data are not available or applicable, the population can be prepared by other methods such as theoretical considerations, estimating, or a mixture of these and past data.

PUT THEM ALL TOGETHER AND GET A MONTE CARLO MODEL

We now have the components for a Monte Carlo Model:

1. Equations to express each possible physical behavior of an operation.
2. Decision rules to predict for certain aspects of the problem which equations are applicable.
3. Random sampling to use for those aspects whose exact behavior is unpredictable.

In a Monte Carlo model the arithmetic must be performed in a highly repetitive fashion. Therefore, if the elements of the above components are arranged in a logical order, the arithmetic is a natural for an electronic computer. A perfectly constructed mathematical model involving only the first two components

should predict exactly the outcome of the physical system it represents. However, if the Monte Carlo technique must be resorted to because factors cannot be predicted exactly, the result we get is only the most probable behavior of the operation. Fortunately, we can also get an indication of how far we might expect the actual system to deviate from this most probable behavior.

NOW FOR AN EXAMPLE

Let us now consider a comparatively simple example of a Monte Carlo study. Crude oil is produced in a field with a maximum production capacity of 200,000 barrels per day. Two pipe lines lead away from the field, one to a tank terminal and the other to a refinery. The maximum throughput through each pipe line is 150,000 barrels per day, and both the refinery and the terminal have 300,000 barrels of crude tankage. Ships desiring to load 100,000 barrels of crude arrive at the terminal at an average rate of one per day, and the scheduled refinery crude runs average 70,000 barrels per day. Neither the scheduled refinery runs nor the ship arrivals can be predicted exactly for any particular day. We want to determine how much of the time tankers are delayed because oil is not available to load them at the terminal and how often crude runs at the refinery must be cut back for lack of oil. We will assume no dock space limitations. Also, let us suppose that we have previously determined (to our great surprise) that the most economical method of operation is as follows:

If the refinery's inventory is insufficient to permit running the scheduled amount of crude, this

deficiency will not be made up later. The opportunity of running this crude will be considered to be lost forever. The maximum amount of crude will be sent to the terminal as limited by the capacity of either the pipe line going to the terminal or the terminal's tankage. The amount sent to the refinery is the maximum possible as limited by 1) crude production capacity left over after filling the terminal order, 2) refinery pipe line capacity, and 3) refinery tankage capacity.

In the following solution, all quantities will be expressed in M barrels.

Let:
- Tr = Today's closing inventory at the refinery.
- Tt = Today's closing inventory at the terminal.
- Yr = Yesterday's closing inventory at the refinery.
- Yt = Yesterday's closing inventory at the terminal.
- Pr = Today's pipe line receipts through refinery line.
- Pt = Today's pipe line receipts through terminal line.
- Rs = Today's scheduled run at refinery.
- Ra = Today's actual run at refinery.
- Na = Number of ships arriving today to load at the terminal.
- Nl = Number of ships loaded today at the terminal.
- Ny = Number of ships left over from yesterday which were not loaded.
- Nt = Number of ships left unloaded at close of today.

The equations stating the physical behavior of our operation are:

A. $Tr = Yr + Pr - Ra$
B. $Tt = Yt + Pt - 100\ Nl$

The decision rules may be expressed as :

1. How many ships do we load?

If $100\ (Na + Ny) \leqq 150 + Yt$ Then $Nl = Na + Ny$
If $100\ (Na + Ny) > 150 + Yt$ Then Nl = Largest whole integer less than $\frac{Yt + 150}{100}$

This says: 100 (Na + Ny) is the amount of oil required if we load all awaiting ships. 150 + Yt is the maximum amount of oil the terminal can load. If the maximum amount the terminal can load is greater than that required to load all awaiting ships, then we will load all the ships. If we do not have enough to load all ships, we load all we can.

2. How much crude from field to terminal?

If $300 - Yt + 100\ Nl \leqq 150$ Then
$Pt = 300 - Yt + 100\ Nl$

If $300 - Yt + 100\,N1 \geq 150$ Then $Pt = 150$

This says: $300 - Yt + 100\,N1$ will be the space in the terminal's tankage before the P/L receipt. If this is less than P/L capacity, we will schedule the P/L to fill the space. If space is greater than P/L capacity, then schedule the P/L wide open.

3. How much crude to refinery?

If $Pt \leq 50$ and $300 - Yr + Rs \geq 150$ Then $Pr = 150$
If $Pt > 50$ and $300 - Yr + Rs \geq 200 - Pt$ Then $Pr = 200 - Pt$
If $300 - Yr + Rs \leq 200 - Pt$ Then $Pr = 300 - Yr + Rs$

This says: $300 - Yr + Rs$ would be the empty space in the refinery's tanks before receiving the P/L shipment if they run the scheduled amount of crude. If the P/L shipment to the terminal is less than 50 and the space at the refinery is greater than refinery P/L capacity, then the refinery P/L is scheduled wide open (150). $200 - Pt$ is the crude production capacity available after satisfying the terminal. If the terminal takes more than 50 and the refinery space is large enough, production capacity limits refinery P/L shipments to $200 - Pt$. In any event, if the space at the refinery is less than the production capacity left over after satisfying the terminal, the refinery P/L is scheduled to just fill the refinery tanks.

4. How much crude does the refinery run?

If $Yr + Pr \geq Rs$ Then $Ra = Rs$
If $Yr + Pr < Rs$ Then $Ra = Yr + Pr$

This says: If the amount of oil available to run $(Yr + Pr)$ is greater than the scheduled runs, then actual run equals the scheduled. If not, then the actual run uses up all the oil available.

If a Monte Carlo calculation is carried out using a sufficient number of random samples, the state of the operation at the beginning should have no effect upon the answer. Let us rather arbitrarily start our calculation with yesterday's closing inventories at the refinery and terminal both equal to 150 and no ships left to be loaded from yesterday. Assume we have gathered past data to develop the two populations representing the refinery scheduled daily crude

run and the number of ships arriving each day. The solution procedure is to draw random samples from the appropriate populations for values of Rs and Na and then calculate today's closing inventory from equations A and B and the four decision rules. Then this procedure is repeated using the new Tt and Tr as the Yt and Yr for the next calculation. New random samples of Rs and Na are drawn for each calculation. Thus the calculation simulates what might actually happen over a period of many days.

Assume our first sampling gives us an Rs = 50 and Na = 2. Then the first day's calculation goes like this:

Decision Rule 1

100 (Na + Ny) - Yt = 200 - 150 = 50 which is less than 150.
Therefore: N1 = Na + Ny = 2

Decision Rule 2

300 - Yt + 100 N1 = 300 - 150 + 200 = 350 which is greater than 150.
Therefore: Pt = 150

Decision Rule 3

Pt = 150 which is greater than 50,
and 300 - Yr + Rs + Pt = 300 - 150 + 50 + 150 = 350 which is greater than 200.
Therefore: Pr = 200 - Pt = 200 - 150 = 50

Decision Rule 4

Yr + Pr - Rs = 150 + 50 - 50 = 150 which is greater than 0.
Therefore: Ra = Rs - 50

Equation A

Tr = Yr + Pr - Ra = 150 + 50 - 50 = 150.

Equation B

Tt = Yt + Pt - 100 N1 = 150 + 150 - 2(100) = 100.

The results of the first ten "days" or cycles are tabulated in the following table. To save space, the inequalities for Decision Rules 3 and 4 have been rearranged, with only the constants on the right.

TABLE OF RESULTS
of
FIRST 10 DAYS OF CALCULATIONS ON EXAMPLE

	Days									
	1	2	3	4	5	6	7	8	9	10
Random Sample										
Rs	50	95	110	65	85	95	50	85	20	80
Na	2	3	1	1	0	0	1	1	0	1
Yesterday's Closing Conditions										
Yr	150	150	105	45	30	0	5	55	70	200
Yt	150	100	50	0	50	200	300	300	300	300
Ny	0	0	1	0	0	0	0	0	0	0
Decision Rule Calculations										
1. 100(Na + Ny) - Yt	50	200	150	100	-50	-200	-200	-200	-300	-200
Therefore N1	2	2	2	1	0	0	1	1	0	1
2. 300 - Yt + 100N1	350	400	450	400	250	100	100	100	0	100
Therefore Pt	150	150	150	150	150	100	100	100	0	100
3. Pt	150	150	150	150	150	100	100	100	0	100
300 - Yr + Rs + Pt	350	395	455	460	505	495	445	430	250	280
Therefore Pr	50	50	50	50	50	100	100	100	150	100
4. Yr + Pr - Rs	150	105	45	30	-5	5	55	70	200	220
Therefore Ra	50	95	110	65	80	95	50	85	20	80
Today's Closing Conditions										
Tr	150	105	45	30	0	5	55	70	200	220
Tt	100	50	0	50	200	300	300	300	300	300
Nt	0	1	0	0	0	0	0	0	0	0

It is not possible to predict in advance how many of these cycles should be calculated in a Monte Carlo Study. The usual practice is to calculate a running average of the variables we are

studying (tanker delivery time and crude cutback in this example). Then statistical tests can be applied to successive running averages which will indicate if the process has been carried out enough times. From a few hundred to several thousand cycles have been necessary in studies reported in the literature.

Assuming we calculate a sufficient number of cycles in the above problem, suppose we find that the average tanker is delayed 0.1 day and the average crude cutback is 500 barrels per day. Since our problem involves some unpredictable factors, these will be the most probable values to expect from the actual system. The calculations will also give us an indication of how far we might expect the actual system to deviate from the average which we calculated.

CONCLUSIONS: By James M. White

This example illustrated the use of Monte Carlo methods in determining how often tankers are delayed in loading and refinery production is cut back. Most of the physical factors were known, but two factors, the frequency of arrival of tankers and the amounts of crude scheduled by the refinery, were uncertain. This uncertainty arose out of the fact that while it was known how often tankers arrived on the average and how much crude production was scheduled on the average, these factors behaved in a random manner, making it impossible to predict exactly what would occur on a given day. Under these conditions, classical methods of computation cannot be used . Trial-and-error methods or scale-model studies are often not practical because they either take too long or are too expensive.

Monte Carlo methods are flexible and relatively inexpensive, and should be well-suited to these situations. The inherent inaccuracy of this technique is more apparent than real and in any case can be kept within arbitrarily small bounds by taking a sufficiently large sample. The method is, of course, subject to the usual risk inherent in the use of mathematical models in describing physical situations. Care should always be taken to avoid too much simplification when using mathematical models, and the results should be carefully checked and verified by independent tests before they are put into practice. Intelligent application of these methods offers a great promise of improvement in management technology and it is to be expected that these techniques will come into more widespread usage in the near future.

APPENDIX

By

James M. White

A popular technique is to use a table of random numbers to obtain a random sample. As a simple illustration, consider the case of a motel which has determined that the average number of guests stopping each night is 3 (ignoring the seasonal and daily fluctuations). It is observed that the Poisson distribution $P(x)=\frac{3^x e^{-3}}{x!}$ predicts the frequency of no guests stopping, 1 guest, etc. We want to obtain a sample of the number of people who stop at this motel on each of a number of successive nights, as part of a study of motel operations. The data is to be simulated rather than obtained from past experience. We prepare a relative frequency

table as follows, from which we develop a correspondence between random numbers and the number of guests, i.e., random numbers 05-19 correspond to the relative frequency of .05 to .20 for one guest per night.

No. of Guests per Night	Relative Frequency	Random Numbers
0	0.05	00 - 04
1	0.15	05 - 19
2	0.22	20 - 41
3	0.22	42 - 63
4	0.17	64 - 80
5	0.10	81 - 90
6	0.05	91 - 95
7	0.02	96 - 97
8	0.01	98
9	0.01	99

Next we draw our sample of random numbers, obtaining 17, 32, 69, 24, 61,31, 03, 48, 60 and 83 for a sample of size 10. The last step is to convert these random numbers into number of guests per night as shown below. For example, 17 lies within the range 05 - 19 and hence the simulation shows that one guest appeared the first night.

Order of Nights	1	2	3	4	5	6	7	8	9	10
No. of Guests	1	2	4	2	3	2	0	3	3	5

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ESTIMATING AND POST-AUDITING DIRECT LABOR SAVINGS IN A JOB-SHOP OPERATION

By

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PART I *

Regardless of the specific techniques business firms employ in evaluating an equipment replacement opportunity, one of the factors always taken into consideration is the reduction in direct labor costs made possible by the acquisition of a new production facility. This is as true for the company that adheres to a two-year payoff requirement as it is for the company that adheres to a more sophisticated approach such as George Terborgh's MAPI formula or Joel Dean's discounted cash flow method. In fact, there is reason to believe that, in a case of pure replacement, direct labor is ordinarily the most important cost factor in the analysis.

Anyone who has ever had the responsibility for making an estimate of the expected direct labor saving knows that the task is an extremely difficult one. This is especially true in those cases in which the machine is used for intermittent production in which small quantities of a variety of products are produced. In this type of operation, no one machine can be identified with any one product; over a period of time, hundreds of different parts may be processed on the unit.

* Part II of this paper, dealing with "Post-Auditing", will appear in the next issue of "The Engineering Economist".- Editor.

The purpose of the first part of this paper is to present the procedure that one firm, which operates under these conditions, employs in making this estimate. The nature of the procedure is such that other organizations may find it appropriate for their own use with little, if any modification.

RECORDS AND REPORTS

The company which serves as the basis for this study is the Ingersoll Milling Machine Company of Rockford, Illinois. Ingersoll manufactures and sells primarily large special machine tools and accessory equipment. All machines produced are essentially milling, boring, or drilling machines or some combination of these types. Its products are special in the sense that almost every machine tool built is engineered to satisfy the requirements of a particular customer for a specific job. As a result of this concentration on special machines, manufacturing operations are non-repetitive. Any one machine being built is rarely an exact duplicate of a machine built earlier. Consequently, lot-sizes are small, and mass production techniques cannot be utilized. In essence, the company engages in a job-shop type of operation.

Because of the nature of its operations, the company has found that machine tools are one of its most important factors of production. The effect of this has been that equipment policy is emphasized because of the inherent contribution a rational policy can make to the firm's well-being. Although no attempt will be made here to describe the company's policy, it is important to state that the management considers the saving made possible in direct

labor by new equipment to be one of the most important factors in any comparison of equipment investment alternatives. To facilitate the making of required estimates, staff departments have developed certain forms, records, and reports which permit accumulation of relevant historical data. These items are described below. The manner in which they are used to forecast probable savings in direct labor will be investigated following this description.

Daily Job Card To record the time spent on various shop orders for cost purposes, a Daily Job Card is used, a copy of which is shown as Figure 1. The Tabulating section of the Accounting department prepares, in advance, an ample supply of these cards for each worker. The preparation consists of inserting the following information:

Department
Machine number
Man number
Operation
Employee's name
Foreman's name

Both the man and machine numbers can be recorded in advance, because every machine operator can be associated with a particular machine. The only exception would be in those cases in which the machine has been replaced, or the man has received a transfer, or the machine has been taken out of service temporarily.

A supply of cards for each machine operator is sent periodically to timekeepers located in shop offices. These individuals are responsible for keeping a sufficient number of the Daily Job Cards in racks located near the operator's machines. At the time he begins his first job, the operator removes one of his cards from the rack and punches in his starting time on a clock set to

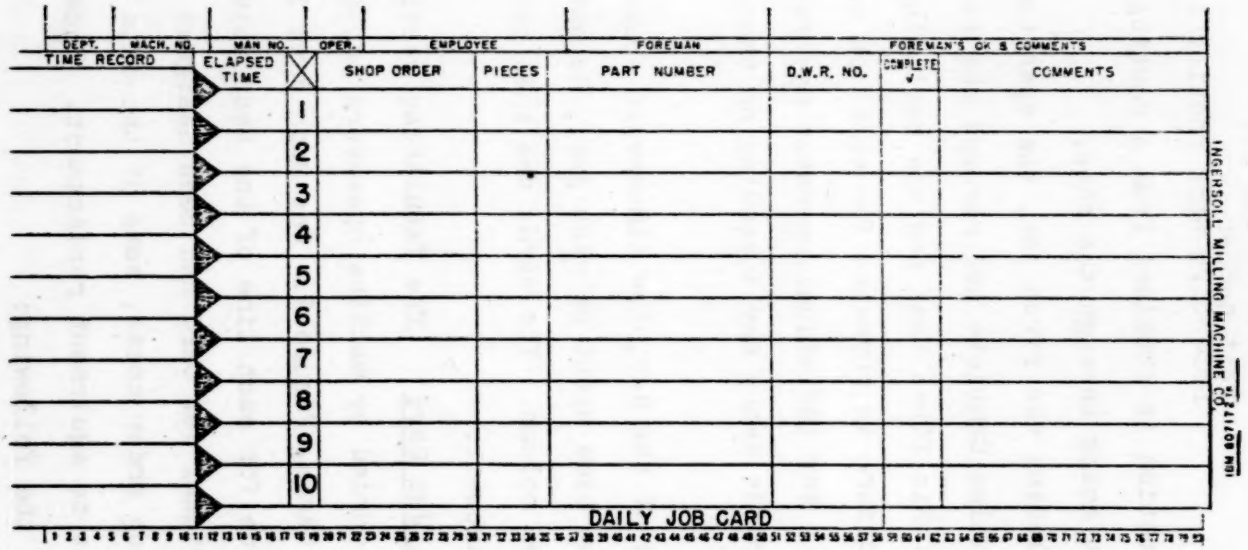

Figure 1. Daily Job Card

record this first entry as "0.0" in the Time Record column. The operator then writes in the following:

Shop Order number
Pieces in the lot
Part number
Defective work routing (if it is re-work)

All this information is obtained from a routing card which accompanies each lot going through the shop.

Upon completing the first job, the operator places a check in the column entitled Complete and records the time which represents both the end of his first task and the beginning of his second. The entire procedure is repeated for each job on which he works during the day. Any individual operator may fill out from one to five of these cards every day depending on the number of jobs he completes.

At the end of the day, the timekeeper collects all the cards and computes the time spent on each job. He enters these times in the Elapsed Time column. The cards are then delivered to the Accounting department.

Individual Job Card The Tabulating section transfers the information, recorded by machine operators on Daily Job Cards, to Individual Job Cards, Figure 2. One such card is made out on a key-punch machine for each line of the respective Daily Job Cards. Since the Individual Job Card had been designed primarily for ascertaining shop order costs, some of the data transferred to it are not relevant to equipment replacement. Those which are relevant consist of the following:

Date
Operation number
Shop Order number

Part number
Quantity produced
Machine hours required
Operator identification

Machine Hours Report The Individual Job Cards are then used to prepare two reports. One of these is the Machine Hours Report which is prepared at the end of each month. The report consists of a listing of machine tools by number and the hours each was in operation during the preceding month. It was developed originally for use by shop management to determine to what extent shop equipment was being utilized. At the same time, it was realized that the information would be of value to equipment analysts who, when estimating direct labor savings, would have to do so on the basis of a given rate of production. Because of the non-repetitive nature of shop operations at Ingersoll, this rate can only be expressed in terms of machine hours.

The way in which the Individual Job Cards are used to prepare this report is as follows. At the end of each week, the cards are automatically sorted by machine number. The hours worked on each machine are totalled and recorded on a summary card. The summary cards, for each machine, are then taken at the end of the month and inserted in a tabulator which determines the respective monthly totals of machine hours and prints the information in final report form. A portion of a typical report is shown in Figure 3.

Report of Direct Labor Hours for Individual Parts This is the second report based on Individual Job Cards. The report is not prepared for all machine tools in the plant. Instead, it is prepared for two categories of machines. The first consists of those machines which are being studied for replacement; the

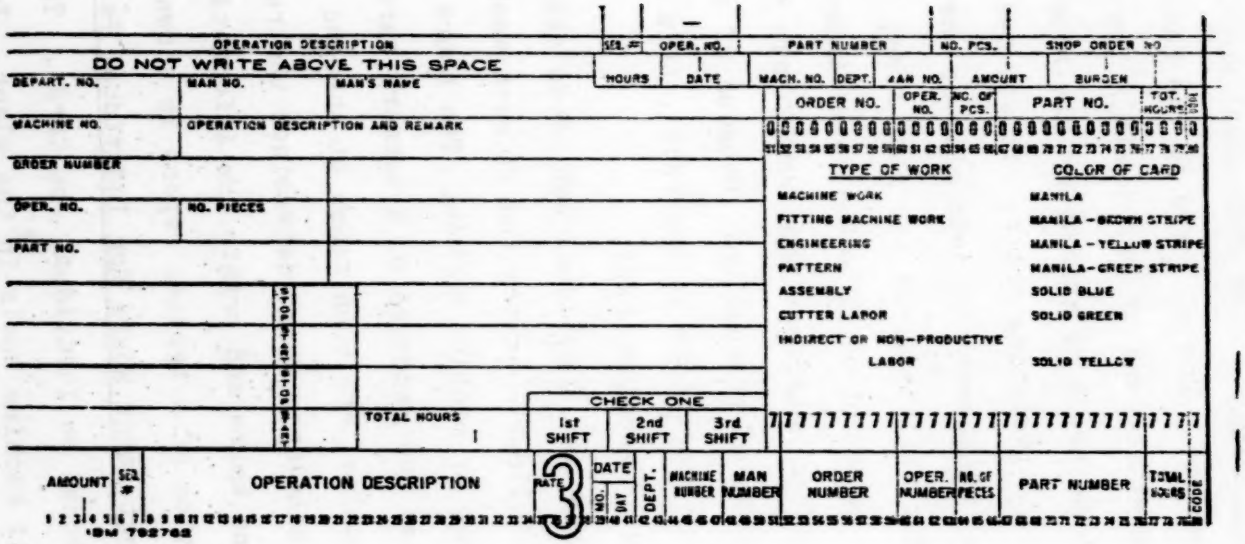

Figure 2. Individual Job Card

THE INGERSOLL MILLING MACHINE COMPANY

REPORT #1 MACHINE HOURS
REPORT DATE

MACHINE NUMBER	HOURS	LABOR-TO-DATE	MATERIAL-TO-DATE	TOTAL COST-TO-DATE
2217	3092			
2228	1680			
2230	109			
2234	214			
2235	3617			
2237	4189			
2238	52			
2240	2303			
2241	2076			
2249	34			
2251	5423			
2252	1071			
2253	5291			
2254	2302			
2255	1625			
2256	2567			
2257	228			
2258	3710			
2259	1404			
2260	3717			
2261	3729			
2262	2153			
2263	4188			
2264	1842			
2265	4172			
2267	34			
2268	4374			
2269	3645			

Figure 3. Machine Hours Report

second, of those machines which have been in the plant six months[1] or less. A list of these machine tool numbers is prepared by the Methods department and sent to the Accounting department with the request that the next monthly report include these machines.

Upon receipt of the list of machine numbers, the Tabulating section key-punches a master card for each machine. All the Individual Job Cards prepared for that month are then taken and inserted in a collater which, governed by the information punched in the master card prepared for each listed machine, pulls out all the Individual Job Cards made out for the machines appearing on the Methods department's list. These cards are then put in machine and part number order by use of a sorter. A tabulator prints up the final report which is sent to the equipment analyst.

Actually, an individual report is made up for each machine. A copy of a typical report is shown in Figure 4. As will be noticed, the heading consists of the following:

Machine number
Machine description
Department number and name

This is followed by columns which contain the following information:

Column	Item
a	Month
b	Day
c	Year
d	Operation number
e	Shop order
f	Part number
g	Number of pieces
h	Elapsed time in hours plus
i	Elapsed time in tenths of an hour
j	Man number
k	Department number

[1] There are exceptions to this rule which will not be discussed at this point.

2377 NORTON CYL GRINDER
DEPARTMENT 80 GRINDER

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
0	17	6	29	28442	D022 28428	1	1	0	279	80
0	17	6	29	28444	D022 28428	1	1	0	279	80
0	17	6	29	19363	115777J	1	1	2	279	80
0	18	6	29	28634	1341445J	1		8	139	80
0	18	6	29	28629	134145J	1		3	279	80
0	18	6	29	28634	134145J	1		3	279	80
0	18	6	29	28572	134145J	1		4	139	80
0	18	6	29	28575	134145J	1		3	139	80
0	18	6	29	28629	134145J	1		8	139	80
0	17	6	29	28572	134145J	1		9	279	80
0	17	6	29	28575	134145J	1		9	279	80
0	17	6	29	28810	1498023J	2	1	7	279	80
0	18	6	29	28272	151022J	1		4	139	80
0	18	6	29	28268	151022J	1		4	139	80
0	18	6	29	19430	152004J	1		5	279	80
0	19	6	29	34820	18186R	1		6	279	80
0	19	6	29	28714	28160R	1		8	279	80
0	19	6	29	28345	28911R	1		7	279	80
0	19	6	29	28350	28911R	1		7	279	80
0	18	6	29	35064	29157R	1		4	139	80
0	19	6	29	35109	29596R	1		7	279	80
0	19	6	29	34821	36874R	1		9	139	80
0	19	6	29	34821	36874R	1		8	279	80
0	18	6	29	35064	48593R	1	1	5	139	80
0	18	6	29	19397	48639R	2		8	139	80
0	19	6	29	34905	62378R	1		7	139	80
0	18	6	29	28479	72214R	2		3	279	80
0	17	6	29	28479	72214R	2	2	4	279	80
0	17	6	29	28731	74271R	1	1	3	279	80
0	18	6	29	28269	77335R	12	1	8	279	80
0	18	6	29	28273	77335R	12	1	8	279	80
0	18	6	29	28269	77336R	12	1	8	279	80
0	18	6	29	28273	77336R	12	1	8	279	80
0	19	6	29	28269	77336R	12	4	0	139	80
0	19	6	29	28273	77336R	12	3	9	139	80
0	18	6	29	28344	78379R	1		5	139	80
0	18	6	29	28349	78379R	1		5	139	80
0	18	6	29	28342	79830R	3		2	139	80
0	18	6	29	29047	79830R	3		2	139	80
0	18	6	29	28342	79830R	3		7	279	80
0	18	6	29	29047	79830R	3		7	279	80
0	19	6	29	28563	87393R	3	2	0	279	80
0	19	6	29	28566	87393R	3	1	9	279	80
0	18	6	29	19312	87455R	1	1	0	139	80
0	18	6	29	19313	87455R	1		9	139	80
0	19	6	29	19252	87844R	1		5	139	80
0	18	6	29	19286	87850R	1		9	139	80
0	17	6	29	19317	88992R	1		6	279	80
0	19	6	29	19287	87571R	2		9	279	80
0	19	6	29	19288	87571R	2		9	279	80

Figure 4. Report of Direct Labor Hours for Individual Parts

In effect, therefore, for certain required machines the equipment analyst has a summary of all the parts processed through the machine during a particular month and the time taken to perform the operation. This information is then used in equipment replacement analyses in a manner to be described.

These then are the forms, records, and reports maintained to assist the analyst in estimating, among other things, the direct labor saving to be realized from the replacement of an existing facility by a new one. Responsibility for making this estimate lies in the firm's Methods department.

SELECTION OF TYPICAL PARTS

Although a record, in the form of Daily Job Cards, exists showing all the different parts processed on a machine and the time required to perform the required operation, all these data cannot be utilized to determine probable savings in direct labor time on the new machine. This is true for a number of reasons. First, the cost of reviewing all these historical data would be prohibitive. Second, what was produced in the past will not necessarily be produced in the future. Finally, it would be impossible to obtain reliable estimates of probable time savings for each of these parts.[1]

For these reasons, the Methods department is responsible for analyzing past production for the purpose of selecting typical

[1] As will be explained later, these estimates are obtained from machine tool manufacturers and suppliers, and they are reluctant to provide estimates on more than six or seven parts because of the work involved.

parts. The parts are typical in the sense that they represent the types of parts that have been produced in the past and will be produced in the future. The time saving expected on a typical part is assumed to represent the saving which will be realized in the production of every part in the category of work represented by that typical part.

The manner in which typical parts are selected is fairly well standardized. It must be borne in mind that these parts are expected to satisfy two requirements. One, they are to serve as the basis on which the expected direct labor saving on the new machine will be computed. Two, they are to be used to establish the required capacity[1] of the new machine. As a result, the parts selected must reflect the entire range of work to be performed on the new machine. For example, these might include the average-sized part, the largest and smallest parts, parts representing various lot sizes, and, depending on the operation involved, parts with large holes, small holes, tapers, threads, etc.

The methods analyst begins the selection procedure by meeting with the concerned superintendent, foreman, and machine operator. Each one is told that the machine is being studied for possible replacement and asked to suggest parts he believes cover the entire range of work going through the machine. The superintendent and foreman rely on experience, judgment, and memory in making their initial suggestions. The machine operator, who is well acquainted with the operations he has been asked to perform on the old machine, also relies on his experience to supplement this list.

1 The word "capacity" is used here to signify the type and size of work the machine can handle.

Following this, prints of the parts are obtained, and a meeting of the superintendent, foreman, and Methods supervisor is scheduled for a final screening of the suggested parts. A detailed study of the prints often reveals that some of the parts are very similar, and all but one of these can be eliminated. Or the foreman may point out that one or more of the suggested parts is not typical of the work that went through his department during the last year or two. The superintendent, on the other hand, may have information to the effect that some of the parts may be typical of past production but not of future production. In any event, the final result of the discussions is an agreement on five to ten parts to be classified as typical. The replacement analysis then continues from this point.

Although the above procedure is the usual one, on occasion a more involved study is required. These occasions are typified by the following situation. There may be reason to believe that some of the typical parts include extreme cases which represent an insignificant portion of the machine's total operating time. Yet, these relatively few extreme cases call for a machine with a capacity greater than would otherwise be required. Naturally, this additional capacity requirement would, most likely, be accompanied by an appreciable increase in the machine's first cost. In order to verify these beliefs, the Methods department will make a comprehensive analysis of all the parts processed on the old machine during the preceding three to six month period.

The analyst begins by sending a request to the Accounting department for the Daily Job Cards of the operators who worked on

the machine during the period under consideration. A list is made of all the different part numbers appearing on these Daily Job Cards. An optional source of this information is sometimes the Report of Direct Labor Hours for Individual Parts. As was mentioned, the Accounting department prepares the first of these reports soon after it has been notified that a machine is to be studied for replacement. It is possible that one or more of these monthly reports has already been prepared by the time the Methods department begins its review of all the parts produced on the old machine. If so, the available reports and Daily Job Cards are both used in the analysis. Daily Job Cards would be requested for that portion of the time period under consideration not covered by the Report of Direct Labor Hours.

After the list of part numbers has been compiled, the engineering department is asked to furnish prints of all the parts involved. These prints are analyzed by the Methods department, and the parts are classified with respect to machine capacity required. Often, it is found that perhaps 95% of the work can be done on a relatively inexpensive machine of standard design. The remaining 5% would necessitate the purchase of a much more expensive piece of equipment. Therefore, the methods analyst then reviews all the machine tools on hand in the shop to determine whether the remaining 5% of the work can be done on existing equipment. Usually it can. As a result, parts representing this work are not included in the typical parts selected to represent the work expected to be processed by the new machine.

This was the case in an actual replacement made by Ingersoll in 1954. The machine involved was a Heald #74 Internal Grinder

which had been purchased in 1942. Although no attempt will be made to present the details of the analysis, suffice it to say that a comprehensive survey, such as the one described above, was made before a final selection of typical parts was agreed upon. This consisted of six parts which are listed below, together with the reasons for their having been chosen:

Part Number	Lot Size	Part Name	Operation	Reason for Selection
18803-X	2	Spindle	Grind holes and end complete. .025 grind stock in holes and .010 grind stock in end.	Large part
11685-R	1	Table feed gear	Grind hole -- .025 grind stock in hole.	Requires large quills
13901-R	10	Cutter spindle	Finish grind hole including relief -- .019 grind stock in hole.	Taper hole
15454-X	8	Spindle sleeve	Grind two 5/16" hole, C/bore in bottom of taper and C/bores in other end. Grind taper hole. .025 grind stock in hole and C/bores.	Long operation
52210-R	4	Sliding gear	Grind hole and clean up end --.025 grind stock in hole and .010 grind stock on end.	Large hole
52211-R	4	Spindle gear hub	Grind hole, C/bores and end complete -- .010 grind stock on end.	Small hole

This particular case of the Heald Grinder, in addition to being used to illustrate the end result of the procedure for selecting typical parts, will be employed to illustrate subsequent points developed in this paper.

After the typical parts have been selected, the next step is to determine the time required to perform the specified

operations on the old machine. Unlike some companies, Ingersoll does not have direct labor standards for its machining operations, and as a result special procedures have been developed to obtain this information.

DETERMINING PAST OPERATING TIMES

The time to process typical parts on the machine being considered for replacement is obtained by two basic methods. One consists of taking stop-watch studies of the operation on the machine; the second calls for estimating the operation time from historical data maintained by the Accounting department.

At this time, the majority of time values, by which the performance of the old machine is measured, are obtained by stop-watch studies. The Methods analyst observes the operation, breaks it down into its various elements, and proceeds to time the operator. Elapsed times for each of the elements of the operation are recorded and analyzed at the conclusion of the study.

All obviously unnecessary work elements are eliminated from the total time taken by the operator to complete the operation. Examples of this type of delay would be the operator's stopping the machine to talk with others or to look for misplaced tools or prints, excessive personal time, and machine breakdown. In effect, therefore, the analyst ignores all but productive elements of work to avoid penalizing the machine for unusual or avoidable operations.

Elimination of unnecessary time results in a figure for actual time taken to set up the machine, machine the part, load and unload the part, and perform the necessary gaging. The analyst, in

evaluating this time, assumes that the operator was working at a normal rate and makes no attempt to adjust the actual time by an efficiency factor. In doing so, the analyst is following a procedure which has Ingersoll management's full approval.

The company's management believes that realistic times are those actually taken in the shop to perform a given operation. It is convinced that supervisory influence and the caliber of shop personnel have combined to bring about a satisfactory level of efficiency, and the methods analyst is instructed to accept this level as being satisfactory. In answer to the criticism that the operator may slow down when being timed, management answers that experience has proven that this rarely happens. The operator realizes that he is not being timed for purposes of establishing a standard or to pass judgment on his performance. Instead, there is only a desire to determine the time required by the average operator to complete the operation. The foreman instructs the operator accordingly and cooperates with the analyst in his attempt to get the information. Of course, there are exceptional cases in which both the analyst and foreman believe that the data obtained are unsatisfactory. For example, if an operator has just been assigned to a machine, it may be that his lack of training or experience will result in unrealistic times. In such cases, the results of the study are discarded.

The second basic method of obtaining the required operating times consists of reviewing available records of past performance. This technique is resorted to when it is impossible to take stopwatch studies of the typical parts. For example, the parts

selected as being typical may not be in the production schedule at the time that the required information is needed, or the methods analyst may find that a new operator is operating the machine at the time and that the results of stop-watch studies are unsatisfactory.

In cases such as this, the Accounting department is relied upon to furnish records from which operating times can be ascertained. Prior to the time that the Report of Direct Labor Hours on Individual Parts was inaugurated, the equipment analyst had only one procedure he could follow. It involved procuring the appropriate Individual Job Cards in the following manner.

When preparing Routing Cards for the processing of individual parts, the Routing section checks its file of Master Routing Cards to determine whether the part under consideration has ever been produced before. If it has, a duplicate of the Master Routing Card is made out for routing the part through the shop. In addition, the shop order number for which the part is now being manufactured is noted on the Master Routing Card. As a result, each part's Master Routing Card contains a list of all the shop order numbers on which the part had been produced. These numbers are important to the methods analyst because all the Individual Job Cards in the Accounting department are filed by shop order number.

Therefore, the analyst looks up the Master Routing Card for each of the typical parts for which he requires operating times and makes a list of the shop order numbers under which they were produced. In selecting these shop order numbers, he must employ some discretion. If the number represents an order that was

completed more than two years ago, Accounting may no longer have the records. In addition, time data that old may not be representative of the machine's current performance. However, the analyst can ordinarily tell from the magnitude of the numbers which shop orders will be recent enough.

A memorandum is then sent to the Accounting department in which the part numbers and their related shop order numbers are listed with the request that the corresponding Individual Job Cards be furnished to the methods analyst. The Tabulating section removes all the cards for the listed shop order numbers from its file and sorts out the required part numbers. These cards are sent to the methods analyst who sorts them to obtain the operation and machine numbers in which he is interested. The analyst has, therefore, Individual Job Cards for each of the typical parts he is studying.

These cards are analyzed by the methods analyst who goes through them and records the past performance of the machine on the typical parts. He is usually successful in obtaining a number of elapsed times for each part. The tabulated times for each part are then analyzed by observation to determine whether all of them are realistic. On occasion, the analyst will notice that one or more are obviously too long or too short; these are discarded. The balance are averaged.

The average elapsed time for each typical part is adjusted by an efficiency factor of 85%. For example, if the average were 2.0 hours for a given part, this would be reduced to 1.7 hours (2.0 x .85). The 15% reduction has been selected to reflect the

presence of avoidable delays such as the ones discarded when taking stop-watch studies. In fact, the 85% figure was arrived at on the basis of experience with stop-watch studies. It had been found that 15% of the operator's time could ordinarily be attributed to unnecessary activities.

Another technique, for obtaining production times on the old machine without stop-watch studies, is related to the one just described in the sense that the source of the data is the same. It will be recalled that the Accounting department begins preparation of the monthly Report of Direct Labor Hours for Individual Parts as soon as it is notified that a machine is being studied for possible replacement. Often, some of these reports have already been issued by the time typical parts have been selected. In those cases, available reports are reviewed to determine if any of the typical parts are included in them. If they are, and it is impossible to take stop-watch studies, the times appearing in the report are used.[1] However, it is usually found that, even if the required parts do appear, a sufficient number of times are not available to compute a meaningful average. As a result, it is necessary to supplement this information with data from Individual Job Cards obtained directly from the Accounting department.

In summary, production times for typical parts on the old machine are obtained by stop-watch study or from historical records. The latter are known to have their limitations: 1) there

[1] These times are analyzed in the same manner as times obtained from Individual Job Cards. They are assumed to reflect an efficiency of 85%. Times that are obviously too long or too short are discarded.

is no way of knowing exactly what portion of the total time can be attributed to unnecessary delays and 2) the recorded times may be subject to the usual shop timekeeping errors. For these reasons stop-watch studies are taken whenever it is possible to do so. In the case of the Heald grinder, referred to earlier, both methods were employed. The results were as follows:

Part Number	No. of Pieces	Set-Up Time	Grind and Load Time	Total Time
11685-R	1	24 Min.	83 Min.	107 Min.
13901-R	10	36	480	516
15454-X	8	30	960	990
18803-X	2	42	408	450
52210-R	4	24	120	144
52211-R	4	24	528	552

At this point, therefore, the Methods department has compiled the following information:

1. Typical parts processed on the old machine.
2. Time required to process each of the typical parts on the old machine.

The next step is to obtain information from potential suppliers of a new machine.

NEGOTIATING WITH SUPPLIERS

Actually, obtaining information from suppliers of new equipment is not always delayed until past production times on typical parts are determined. Usually the Methods department asks the Purchasing department to open preliminary negotiations with stipulated manufacturers as soon as typical parts have been selected. On occasion, however, this step awaits the compilation of production times.

Manufacturers approached are those selected by the Methods department when investigating possible sources of a replacement machine. The representative of each of these companies, upon his arrival, talks to the supervisor of the Methods department, who acquaints him with the problem. The old machine is described and reasons for considering its replacement given. Typical parts to be processed on a new machine are discussed, and blue prints of each part are furnished to the salesman. If the blueprints of the parts do not adequately describe the material, amount of stock to be removed, and finish required, this information is supplied. Lot sizes for each part are given, and the method of inspection is described. In brief, all information is made available which will aid the salesman's firm in recommending the best possible machine, fixtures, and tooling for the work to be done on the representative parts. Potential suppliers are invited to send their engineering representatives to analyze the problem if they feel this is necessary.

In addition to being asked to recommend the best alternatives they can make available, manufacturers are asked to supply estimates of the time required to process the typical parts on their respective machines. Ingersoll management believes that no one is better qualified to furnish dependable information on the production potential of a machine tool than the builder of that tool. For that reason, the Methods department when requesting proposals insists on dependable time estimates for each of the typical parts. These estimates serve a twofold purpose. First, they permit the company to measure the saving in direct labor that the required

investment will make possible. Second, they provide a sound standard by which to evaluate the effectiveness of day-to-day operations after the equipment is purchased. To insure that these estimates are dependable, Ingersoll insists that the supplier guarantee that his machine will perform the specified operation in the estimated time under the stipulated conditions.

The policy of guaranteed production times was enforced in the negotiation for a replacement machine for the Heald grinder. Two manufacturers were approached as possible suppliers of a new machine -- the Alpha Company and the Beta Company. In the negotiations that followed, the representatives of these firms were acquainted with the machine capacity required, based on the six typical parts selected, and all other data they would require in order to make a proposal. After weeks of careful study, the Alpha Company informed Ingersoll that none of its grinders had a grinding stroke sufficient to handle all the representative work, and hence they would be unable to quote on a replacement machine. Beta on the other hand proposed a machine that was capable of processing five of the six typical parts. This, however, was not satisfactory to the Methods department, and Beta was asked to give the problem further study. Finally, months after the initial meeting between Ingersoll and Beta representatives, the supplier submitted a firm proposal for a machine to perform required operations on all six typical parts. This quotation was accompanied by estimates for operation times on the typical parts. Although the Methods department asked that estimates be submitted for set-up and grind and unload time, Beta replied:

"Set-up time includes setting the jaws and chucks, changing wheels and wheelheads, and setting the workhead for either straight or table grinding. We cannot estimate set-up time, because we have no way of knowing the sequence of your jobs. We suggest that you use your present figures for set-up time."

The methods analysts reviewed the design of the proposed machine and decided that assuming no change in set-up time was justified. Therefore, they added these past times to Beta's estimated grind and unload times to arrive at a total. This is shown below:

Part Number	No. of Pieces	Set-Up Time	Grind and Load Time	Total Time
11685-R	1	24 Min.	17 Min.	41 Min.
13901-R	10	36	200	236
15454-X	8	30	320	350
18803-X	2	42	218	260
52210-R	4	24	80	104
52211-R	4	24	184	208

Beta described grinding time as including time for dressing the wheel, grinding the work, and gaging the work. Loading time included loading, unloading, and indicating the work.

Thus, at this point, the methods analyst had dependable data on which to base his estimate of the probable annual direct labor saving.

DETERMINING THE ANNUAL DIRECT LABOR SAVING

In the discussion of typical parts, it was stated that "the time saving expected on a typical part is assumed to represent the saving which will be realized in the production of every part in the category of work represented by that typical part." It is

further assumed that the lot size associated with each typical part represents the lot size to be associated with every part falling into the category of work represented by that typical part. Both assumptions are justified by the manner in which typical parts are selected. But before the average annual saving in direct labor can be estimated, it is first necessary to determine what portion of the total production time can be attributed to each of the categories of work. In effect, a weighted average of the expected saving on each typical part must be computed.

The per cent of total operating time represented by each typical part is estimated by a committee of three individuals. These consist of the supervisor of the Methods department, the superintendent of the department in which the old machine is located, and the foreman of the production center in which the old machine is located. The estimate is based primarily on their experience and judgment. One or more meetings are held to decide what percentage should be assigned to each Work Load Class represented by the respective typical parts. These percentages are then applied to the estimated saving for each Work Load Class to arrive at the average saving. The entire procedure can be illustrated by showing the manner in which the average per cent saving in direct labor was estimated for the Beta grinder.

First, the anticipated reduction in direct labor time for each Work Load Class was computed on the basis of a comparison between past and future production times for the appropriate typical part. The manner in which this was done is as follows:

Part Number	Work Load Class	Lot Size	Production Time: Present Machine	Production Time: Proposed Machine	Time Saved	Per Cent Reduction
(a)	(b)	(c)	(d)	(e)	(f)	(f ÷ d)
11685-R	1	1	107 Min.	41 Min.	66 Min.	62
13901-R	2	10	516	236	280	54
15454-X	3	8	990	350	640	65
18803-X	4	2	450	260	190	42
52210-R	5	4	144	104	40	28
52211-R	6	4	552	208	344	62

Next, the estimated per cent of total production time on the old machine for each Work Load Class was applied to the per cent saving for each of these classes. The respective estimated per cents of total production time for each Work Load Class and the manner in which they were used to arrive at the average saving in direct labor are as follows:

Work Load Class	Per Cent of Total Production Time	Per Cent Reduction in Direct Labor Time	Contribution to Average Per Cent Saving in Direct Labor
(a)	(b)	(c)	(b x c)
1	4	62	3
2	19	54	10
3	36	65	23
4	16	42	7
5	5	28	1
6	20	62	12
Total	100		56

The average reduction in direct labor hours expected from the replacement of the old machine was therefore approximately 56%.

In all cases, a per cent such as this is then applied to the average hours the machine is in operation per year. For purposes of the report to be submitted to management, the Methods

department is instructed to use the hours the machine has been in operation during the past year. This information is obtained from the Machine Hours Report. The machine operator's hourly rate is then obtained from the Accounting department and applied to the annual saving which is now expressed in hours. This yields the annual dollar saving in direct labor costs.

The preceding year's operating time for the Heald grinder was approximately 2500 hours. The estimated saving in direct labor hours would therefore be (2500 hours x .56) or 1400 hours. The operator's average hourly rate was $1.98, thereby yielding a saving of (1400 x $1.98) or $2,770 per year. However, work was to be transferred from an old Ingersoll grinder to the new machine if it were purchased. The methods analyst, superintendent, and foreman estimated that this would amount to the equivalent of 1200 hours of work on the old machine. Since this work was considered when selecting typical parts, the same average per cent saving was employed. Because the same hourly wage rate applied, this would provide an additional saving in direct labor of (1200 x .56 x $1.98) or $1330 per year. In total, therefore, the new Beta grinder would permit an annual saving in direct labor of $4,100.

Actually, the manner in which the direct labor saving is determined does not yield a figure which represents the <u>average</u> annual saving to be realized from an investment in the new asset. The new equipment will accumulate deterioration and obsolescence during its service life, and hence the computed figure is an estimate of the magnitude of the first year's reduction in direct labor costs. At Ingersoll, the effect of future deterioration

and obsolescence is considered an irreducible factor which is given consideration by management in its evaluation of the replacement proposal. Other firms may find it more expedient to provide for this effect by adjusting their rate of return requirement or estimating the rate at which deterioration and obsolescence accumulate.[1]

SOME GENERAL OBSERVATIONS

This then is the manner in which a typical manufacturer, engaged in intermittent production, estimates the saving in direct labor to be realized from the replacement of an existing production facility. It will be noted that two simplifying assumptions are made. First, the rate of production on the new machine will be equal to that on the old machine during the year preceding the replacement analysis. Second, appropriate hourly wage rates are those in effect at the time the study is being made. However, it is important to point out that these assumptions were approved by management solely for use by the Methods department. They are the result of a belief that it is impossible to predict accurately the magnitude of these factors for a future period of time ranging from ten to fifteen years. This is especially true of the future level of operations because of the wide fluctuations in demand for the company's product. Consequently, the preliminary analysis made by the methods analyst is based on the

[1] Companies using the MAPI method find it necessary to estimate only the next-year saving. The formula on which the method is based provides for future deterioration and obsolescence.

supposition that present conditions reflect those of the future. The president of the company realizes, however, that probable changes in the future cannot be ignored. Hence, in the final analysis, for which he is responsible, data made available to him by the Methods department are interpreted in the light of his expectations of the future. As a result, a decision regarding the acquisition of new equipment is based on a number of factors other than those taken into consideration by the methods analyst.[1] Insofar as direct labor costs are concerned, the president gives serious consideration to anticipated changes in the level of operations and wage rates. The manner in which these irreducibles are evaluated is outside the scope of this paper and hence will not be discussed here. But it can be said that the nature of these and similar factors will determine whether replacement is encouraged or discouraged.

[1] Although this paper deals only with the factor of direct labor, the methods analyst does consider other items of cost and revenue which are being ignored here.

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Review Article

JUDGING PROFITABILITY BY VENTURE WORTH OR INCREMENTAL PRESENT WORTH *

By

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Persons charged with safeguarding company profits through wise screening of proposed expenditures welcome a method of profitability evaluation that correctly considers the effects of all economic variables and is easy to understand and use as well. Most methods now in use emphasize either accuracy or simplicity, but to date the two characteristics have proved generally incompatible. J. Happel with his venture worth and F. W. Winn with his incremental present worth have contributed significantly to the field in presenting a comprehensive method which gives an understandable profitability measure. The method still requires considerable straight thinking and arithmetic, but a correct expenditure decision is worth the effort. Both articles will be discussed collectively here despite their differences in scope and presentation, as the basic method presented in each is the same. The method employs the concept of the time value of money -- a dollar earning now is worth more than a dollar promised any time in the future -- in considering the effect of timing as

* Literature cited:

GRANT, E. L.: Principles of Engineering Economy, 3rd ed. Ronald Press, New York, 1950. 623 pp. $5.

HAPPEL, J.: "The Venture Worth Method for Economic Balances", Chemical Engineering Progress, Vol. 51, p. 533, December 1955.

WINN, F. W.: "How to Invest Your Capital for Profits", Petroleum Refiner, Vol. 35, p. 199. July 1956.

well as magnitude of expenditures and income on the value of a proposed project. If one borrowed $5000 on a five year note at 6% annual interest he might pay $1187 at the end of each of five years or $6690 in a lump sum after five years to repay the principal plus interest as calculated by compound interest formulas. In either case, considering the time of borrowing as the present, the present worth of either repayment is $5000 and the earning rate to the lender is 6%. Through the use of compound interest formulas income and disbursements occurring at any time can be converted to a common, comparable basis, i.e., present worth, at a given interest rate. Compound interest formulas, their bases, and uses are discussed in detail in E. L. Grant's "Principles of Engineering Economy" and other economics texts, and briefly in the subject articles by Happel and Winn. In the determination of venture worth or incremental present worth a minimum acceptable earning rate based on company earnings from similar projects is established, and the calculation is as follows: from the sum of the credits of the present worth of all net income after taxes and before depreciation, the present worth of all tax credits receivable under the depreciation schedule used, and the present worth of the project salvage value after taxes is subtracted the sum of the debits of the initial capital investment and the present worth of the earnings required of working capital. The difference is the project venture worth or incremental present worth. In an analysis of the steps in the calculation the credits at actual value can be considered as payments at the stipulated interest rate on a hypothetical debt, and the amount of the debt

that could be removed by those payments is their present worth. When this amount is equal to or greater than the actual expenditure, converted to equivalent present worth dollars, the minimum acceptable earning rate is being equaled or exceeded, respectively, and the investment is attractive. The highest value of venture worth provides the basis for selection among mutually exclusive alternatives. Happel presents a method of determining an equivalent fractional yearly earning rate above the minimum attractive earning rate for ranking acceptable projects competing for available funds. Also included in the method is a procedure for evaluating risk through application of a factor for probability of success or failure.

Both Happel and Winn contend that their method infers reinvestment of earnings at the stipulated interest rate. It is felt that the foregoing treatment in which the disposition of profits received as payment of investment plus interest is not considered, is more realistic and understandable.

The basic method discussed is most applicable to the evaluation of complete profit earning projects. Happel and Winn present additions to the method which include expressions for differentiation to obtain optimum values for variables, two approximate compound interest formulas, a method intended for determination of the detail and time justified for a cost estimate, and a general discussion of considerations entering into economic evaluations and several other methods of gauging profitability. Also included in both articles are excellent examples demonstrating different applications of the method and its enlargements.

In summary, it can be said that the method involves a series of calculations which are straightforward for one familiar with compound interest economics, gives an understandable and defensible answer regarding economic advisability, and accurately considers the time value of money in any schedule of receipts and disbursements or length of project life. The method avoids a major disadvantage of straight present worth comparisons of alternative projects where equal project lives must be used in the comparison, and includes a provision for evaluating the effect of risk.

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Review

SCIENTIFIC INVENTORY MANAGEMENT SIMPLIFIED - THE ECONOMIC ORDER QUANTITY

Publication of the General Services Administration
Federal Supply Service *

The booklet under review is apparently one of a series of booklets on the tools of Scientific Inventory Management. It deals, however, with only one of these tools -- economic order quantity.

The booklet has been written with the stock replenishment systems of various Government agencies in mind. In such systems the question of how much to order arises. The booklet states that the economic order quantity (E.O.Q.) answers this question by yielding the "amount to order which will keep the total costs at a minimum".

The format is good; the booklet is interesting and practical. It should help those whose task it is to determine how much to order by making the operation more definite and consistent. The booklet points out that items high in cost and volume should be ordered in quantities smaller than items low in cost and volume. Most systems of stock replenishment now in use in Government agencies, the booklet claims, do not give adequate consideration to these points.

In presenting this material on E.O.Q., every effort has been made to keep it simple, and many handy tables and charts have been

* Available through the Superintendent of Documents, United States Government Printing Office, Washington 25, D. C.(45¢)

developed to make the application of E.O.Q. painless. Unfortunately, the attempt to simplify has created some confusion. Perhaps this is unavoidable. To keep it simple, the assumptions underlying the E.O.Q. formula are not given until after the benefits of using E.O.Q. are described. It is felt that these assumptions should be clearly stated -- and at an early stage.

Little is said of safety allowances other than that it is a related problem, yet the setting of inventory levels must be a combination of both safety allowances and E.O.Q.

The E.O.Q. formula considers two different sets of cost factors: those which increase as inventories increase, and those which decrease as inventories decrease. Among the former are: interest, depreciation,risk, obsolescence, storage, etc. Among the latter are: quantity discounts, freight differentials, and procurement costs. The E.O.Q. is that quantity which balances these two types of cost factors.

The simple E.O.Q. formulation,as given in the booklet, is based upon several assumptions:

(1) that the quantity ordered arrives when the stock has just been depleted;

(2) that the rate of usage is uniform;

(3) that the expense of procurement is a constant amount for each order placed;

(4) that the interest, risk, depreciation, obsolescence and storage charges may be combined into one percentage figure.

In most circumstances these assumptions are not valid. Usage rates, for example, are usually not uniform. Only in the case of uniform usage rates will the future demand be known.

And the anticipated demand needs to be known before the E.O.Q. can be determined.

In many instances, however, the simple E.O.Q. formulation can be used. The total variable cost curve in the neighborhood of the economic number of orders is relatively flat. The cost will only increase slightly, therefore, with moderate changes in the amounts ordered. It is this characteristic flattening of the total variable cost curve that makes the simple E.O.Q. formulation useful as a guide in ordering. Furthermore, this characteristic allows the use of approximate procurement and carrying costs -- costs which are usually difficult to determine exactly.

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Book Review

ECONOMIC MODELS*

This is an excellent introduction to quantitative procedures in economics for a person with engineering training (or a general college education with equivalent mathematics to that of an engineering course). The author modestly spells out the introductory-text purpose of the book, but it is possible that he may have understated the necessity for having a working memory of calculus, which is essential for Chapter 4, Nonlinear Models, and Chapter 5, Continuous Dynamic Models. The rest of the book can be handled by a person with reasonable facility in elementary algebra. Problems and answers provide useful exercises for a conscientious reader. Good, short reading lists are appended to each chapter.

The book is divided into two parts which are largely unrelated in exposition until the last chapter, Multiple Relations. The first part, Mathematical Models, discusses a wide range of mathematical models of economic relationships classified by their mathematical character. The models are of two kinds, of course, those pertaining to one commodity market and those covering the entire economy (in abbreviated form). Many engineers from time to time have to comment on and evaluate both kinds of problems, those of forecasting the price and output of a commodity under

* E. F. BEACH: John Wiley & Sons, Inc., New York, 1957. 227 pp. $7.50

different conditions and also to estimate what the entire economy is up to.

The 34 models are not listed by economic subject anywhere, nor is the index very helpful ("demand" and "supply" do not appear as index subjects). Thus, this introductory text has to be read or searched through for comments on any one topic. Furthermore, the models are related primarily to general theoretical problems rather than more specific applications which the author might have cited even though he did not discuss them. This could be corrected easily to make the book more useful as an introductory handbook (even though it expressly denies that it provides procedures of computation). This criticism is also true of Tintner's text* which is also organized along mathematical lines and lacks an index which treats the economic topics adequately or lists examples by economic subject.

The second part, Econometric Models, is comprised of three chapters of introduction to, or review of, elementary statistical regression theory, plus the last chapter on Multiple Relations, which shows applications of statistical regression theory to mathematical economic models and discusses the more important problems involved. The three statistics chapters may be sufficient for appreciation of statistical techniques and problems if one has never studied statistics before, but these chapters provide a refresher for one who has not used such statistics for some years. Even for such an individual, however, good opportunities were lost to illustrate the material with applications to

* GERHARD TINTNER: Econometrics. John Wiley and Sons, Inc., New York, 1952. 370 pp. $5.75.

economic models, especially the discussion of multivariate regression. (It would have been helpful to cite Tintner's econometrics text for this chapter because of its collection of many illuminating illustrations and multivariate techniques.)

The last chapter is the climax of the book, because most economic problems imply models involving simultaneous equations. The statistical estimation of parameters of such equations is fraught with pitfalls. This chapter is an excellent introduction to these difficulties and some of the methods used to solve or circumvent them.

This book does not include economic models typical of linear programming or operations research. These, of course, are now treated in other texts, but in a later edition a chapter perhaps should be added to treat these in perspective with other economic models.

The book does not pretend to make an accomplished practitioner of its reader. It merely hopes to lead him efficiently into the field. It also has another valuable strength which the author modestly fails to emphasize. This is that it can serve to make the reader a reasonably intelligent consumer of econometrics, which is flowing in accelerating amounts to the higher echelons of management. Unless one has had this sort of introduction, he cannot hope to be a reasonably confident and intelligent consumer. As a consumer of engineering reports, an engineer would insist on preparing himself to a much greater degree than this modest book would prepare him, for using

econometric reports. In view of the surge toward econometric reports, this level of preparation is becoming disproportionate.

Paul W. McGann

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SIXTY-SIXTH ANNUAL MEETING

THE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

The American Society for Engineering Education will hold its Sixty-Sixth National Meeting at Berkeley, California, June 16th - 20th, 1958.

The Engineering Economy Division is arranging a program of conferences for Monday, June 16th, and Thursday, June 19th, on subjects related to this field of professional interest. Papers and discussions will be presented by outstanding men.

A joint luncheon, with an outstanding speaker, is being planned by the Division for Wednesday, June 18th.

Announcements of the conference topics and speakers, and of final arrangements for the joint luncheon, will appear in the forthcoming issues of this journal.

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